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THE LOCATION OF STRESS IN CLOTHING

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DEFENCE RESEARCH ESTABLISHMENT OTTAWA
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ABSTRACT

This paper reports the results of a study to determine where stresses occur in clothing, and thus seams, and what stances cause the maximum stresses in typical Canadian Forces clothing. It was found that crossing the arms in front with the hands on the opposite shoulders creates the greatest stress in the shirt or coveralls back. This stance imposes stress in the lower part of the back armhole seam. Raising the arms over the head creates a stress point at the back armscye. Squatting is the stance which causes the greatest stress in the trousers and coveralls, this occurring along the upper, inner leg and crotch area/seams.

RESUME

Cet exposé porte sur les résultats d'une étude ayant pour but de déterminer quelles positions imposent les plus grandes contraintes sur les vêtements typiques des Forces canadiennes, et dans quelles parties de ces vêtements, et donc quelles coutures, elles se produisent. On a constaté que croiser les bras sur la poitrine, les mains placées sur les épaules opposées, crée le plus de tension dans le dos d'une chemise ou d'une salopette. Cette position impose une contrainte dans la partie inférieure de la couture arrière de l'emmanchure. Lever les bras au-dessus de la tête cause de la contrainte dans la partie arrière de l'emmanchure. L'accroupissement est la position qui crée la plus grande tension dans les pantalons et les salopettes, et ce dans la partie intérieure supérieure de la jambe et dans l'entre-jambes et la couture de l'entre-jambes.

INTRODUCTION

In a DCGEM-sponsored task to determine if alternative seam types could replace the commonly-used double lap seam in the Canadian Forces (CF) clothing, the question was raised as to how strong seams have to be in clothing. In a 1952 study, Frederick at Natick, had stated that the seam strength, for the end uses he was considering, should be 80% of the fabric strength. The recommendation arising from the DCGEM-sponsored task (Crow and Dewar, 1983), was that the criteria of 80% seam efficiency be re-evaluated because of the progress made in technology since Frederick's work, resulting in stronger, more durable sewing threads, seams and fabrics.

Therefore, this study was undertaken: to find a technique to determine where maximum stresses in clothing, and thus seams, occur; to find a reliable method to measure these maximum stresses; and to determine where the maximum stresses occur in the seams of various CF garments which presently have double lap seams and the magnitude of these stresses.

An earlier paper (Crow and Dewar, 1984) reviewed the literature for methods to determine where stresses occur in clothing; what stances cause maximum stress; how to measure these stresses. It described various approaches tried and the final selection of methods used to both qualitatively and quantitatively measure stress in clothing.

This paper will give the results of the next phase of this study, that is, where maximum stresses occur in typical CF clothing and what stances cause these stresses.

METHOD USED

The method (Crow and Dewar, 1984) selected to determine where stresses occur in clothing was to make garments from rubber dam or sheeting which had slits cut in it. These slits opened or gaped when stressed, clearly showing stress patterns for any particular stance.

Since the CF garments with double-lap seams were either two piece, (combat shirt and trousers), or one piece (coveralls), a long-sleeved T-shirt, trousers and coveralls were made from rubber sheeting. The sheeting garment-pieces were backed with a non-woven carrier and then slits cut in the sheeting, according to the pattern shown in Figure 1, using a die, as shown in Figure 2. Half the pattern pieces had the slits cut horizontally and the other half had the slits cut vertically so that the major axis of stress could be detected. The garment pieces were then sewn together and the non-woven carrier cut away at the seams.

It is noted that, after about a year, the rubber deteriorated and became quite fragile, tearing readily. The rubber dam material was continued to be used as no other material with similar properties and longer shelf life could be found.

STANCES TAKEN

The literature review (Crow and Dewar, 1984) indicated that the stances which would give the maximum stresses are fully bending the elbow (sleeve), crossing one's arms in the front (shirt back), bending the knee (trouser leg), sitting with the knees up (seat of the trousers) and bending over for maximal spinal curvature (back of the coveralls). A series of stances were taken, and recorded with photographs to see if these stances were in fact the ones which did give maximum stress. The results of this part of the study will now be given and discussed.

THE SHIRT

THE BACK

The slit-rubber shirt was donned over a tight-fitting, long-sleeved knitted T-shirt. Figure 3(a) to (f) shows the subject, wearing the T-shirt with the slits running vertically, in the neutral position and in

various stances. Figure 4(a) to (c) shows the subject wearing the T-shirt with the slits running horizontally in the neutral position and in two of the stances shown in Figure 3. In the neutral position, Figure 4(a), the slits gap slightly due to gravity.

It can be seen that most of the stress in a shirt back is across, rather than down the back. The regions of horizontal stress vary with the stance. When the arms are raised over the head, the stress occurs in the mid-region of the back. When one bends over, horizontal stress occurs in the area of maximum curvature of the back. Although not shown here, when the subject bends over to touch the floor, the whole back area, which is now curved shows some degree of horizontal stressing. When the arms are held in front of the body, it is the upper third of the shirt which is stressed. The posture or stance which imposes the maximum stress on the back of the shirt is when the arms are crossed in front, parallel to the floor, the hands on the opposite shoulders.

THE SIDE VIEW OF THE BACK AND ARM

Figure 5 shows the subject in various stances as photographed from the side. The area of greatest stress in the back arm seam appears to occur at the point of greatest curvature in the back armscye when the arm is held over the head and along the bottom half of the armscye or armhole when the arm is held in front of the body. When the arms are held over the head, the sleeve slips down the arm and no stresses occur in the sleeve. However, when the elbow is bent, as shown in Figure 5(b), it and the shoulder act as tie points, which cause stress to occur along the outer part of the upper arm.

THE ELBOW

Figure 6 shows that the maximum stress in the sleeve occurs when the elbow is fully bent. Stresses occur horizontally and vertically over the elbow area. The distortion of the slit rubber in the lower sleeve is due to wrinkling rather than tensile stresses. Similar distortion or compression of the slits can be seen in the upper front of the T-shirt.

THE TROUSERS

The patterns of stress in the trousers are more complex than in the shirt. After the subject took a series of stances, it was found that the greatest and most widespread stresses occurred when the subject sat with the hips and knees fully bent and the knees spread apart. Since it was difficult to photograph all areas of the trousers in this stance, less severe stances were taken and photographed.

Figure 7 shows the front and back views of the subject in the neutral position. Ballet tights were worn under the slit-rubber trousers. Slight horizontal stress appears over the buttock and abdomen areas.

When the subject bends over (Figure 8) the back waistline of the trousers slides easily down the back in an arc from hip bone to hip bone. This arc is deeper when the crouching stance is taken, as shown in Figure 9(b). Similar amounts of horizontal and vertical stressing occur in the buttock area in the bent-over stance. Again, this stress is slightly more severe in the crouching stance when the hips are bent to a greater degree, making the buttock area wider and longer.

There is a large V-shaped compression area from the side of the buttocks to the side seam, as seen by the buckling of the rubber in Figure 8(a). This area is directly over the side of the ball-in-socket hip joint. In the crouching position, this compression area is still there but is smaller in area as the hip joint is now more sharply bent.

It is interesting to note that in the bent-over stance, stress occurs down the back leg from the hip to approximately the back of the knee (Figure 8(a) and (b)). Although the bottom of the trouser legs do move up to accommodate some of the increased length of the bent hip and leg, the knee tends to catch the trouser leg (partially due to its protuberance and partially due to friction) as shown by the wrinkles at it, thus limiting the length of trouser leg which now must accommodate the increased length along the back of the leg. The crotch of the trousers also moves up and can limit the degree to which the trouser legs can move into the buttock area. Diagonal folds can be seen radiating from the fullest part of the buttock toward the knee (Figure 8(c)). This is partly due to the trousers being stretched between the tie points of the buttock and knee, and partly due to the enlarged, contracted front thigh muscles pressing against the trouser leg.

Figure 9(a) shows the stresses in the front of the trousers when the subject crouches. Stress occurs across the stomach where it naturally protrudes. Wrinkling occurs in the groin region of the trousers where the

hip bends. The thigh increases in circumference due to the flexing of its muscles, creating horizontal stresses along the front thigh part of the trouser leg. Vertical stresses occur from the kneecap to about half way up the thigh due to "unfolding" of the skin just above the knee when it is bent. This gives a localized increase in length and thus stress over the top of the knee. The greatest stress in the knee area is a band, approximately the width of the kneecap, running vertically over the knee. There is some horizontal stress across the knee which is caused by the increased circumference of the knee and the increased curvature of the knee when it is bent. Folding of the trousers occurs at the side of the knee. The side views, Figure 9(c) and (d), show no stress along the upper side seam. This is because the outer part of the thigh remains relatively constant in length and because there are no extensive muscles here to flex and thus, protrude. There is some stress in the front of the lower trouser leg caused by the stretching of the trouser leg between the calf and the tie point of the knee. The fabric is "clamped" between the upper leg and the calf creating the lower tie point. Also, the trouser leg does not slide easily up the leg due to friction.

The stressing in the crotch and lower buttock areas can be seen in Figures 9(a) and 10 respectively. When the subject is crouching, stress occurs along the inner back thigh, this area probably experiencing the greatest stress of all in the trousers. When the subject spreads his legs apart (Figure 10), it can be seen that this area along the inner back thigh continues to have the greatest stress. There are three tie points here, the buttock, the crotch and the knee. The tie point at the crotch is similar to the one created at the deepest point of the armhole. This causes wrinkling and stress to radiate out diagonally from the crotch along the inner leg seam. It has been found (Emanuel and Barter, 1957) that the greatest increase in body dimensions (as measured from just below the waist to the mid-thigh) occurs when a subject goes from the neutral standing position to a sitting position where the knees are drawn up to the chest. Therefore, even if the back waist-line of the trousers does move down the back by a couple of centimeters, it is not enough to compensate for the large increase in body length in this area.

Finally, in Figure 10 it can be seen that the lower trouser leg is relatively unstressed since the bottom of the trouser leg is free to move up the leg, unlike when the subject was in the crouching position. There is some gaping of the rubber slits at the knee, but this is due to distortion caused by the slit rubber draping from the bent knee, rather than from stress between two tie points.

THE COVERALLS

Figure 11 shows the front and rear views of the subject wearing

the slit-rubber coveralls, again over the knitted T-shirt and tights. The left half of the suit has the slits running horizontally, the right half vertically. There is some gaping of the horizontal slits in this neutral stance, but it is caused by the draping of the slit material due to gravity.

Figure 12 shows various stances similar to those taken when the subject was wearing the rubber T-shirt. The stress patterns in the 'shirt' back of the coveralls are similar to those of the T-shirt, with the stance of crossing the arms in front causing the maximum stress across the back (Figure 12(a)). When the subject has his arms out in front of him, crossed or straight out in front, the only stress which occurs in the body of the coveralls is in the 'shirt' back area (Figure 12(a) and (b) respectively). However, when he raises his arms above his head or bends over, increasing the overall length of the body, stress occurs in other areas of the coveralls. This is because the coveralls are one piece and cannot separate at the waist as the shirt and trousers did to allow for this increased length of the body. When the subject raises his hands above his head (Figure 12(c)), the crotch and the two upper arm muscles form a triangle of tie points. This is evident from the wide "arc" in the coveralls across the back extending up into the sleeve. This arc is outlined with folds and slight stress between the crotch and underarm and in the upper sleeve. Although the long sleeve does move down the arm to compensate for some of the increased length, stress still occurs in the cap of the sleeve as it is pulled into the main body of the coveralls and the upper arm muscle protrudes. In the "trouser" part of the coveralls, the stress is horizontal over the protruding buttock region and vertical in the lower back as this area is stretched between the arm and the crotch.

When the subject bends over (Figure 13), longitudinal stress patterns occur from the neck to the calf due to the increase in length of the body. Horizontal stress occurs across the upper back down to the buttocks, diminishing in intensity as the curvature across the back decreases. Again there is some stress horizontally across the sleeve cap and some vertical stress in the armscye region since the scye point of each sleeve limits how much the sleeve can move 'into' the back of coveralls, and thus acts as a tie point for this particular stance.

When the subject crouches (Figure 14), the stress patterns in the 'trouser' part of the coveralls are similar to those of the trousers, as described earlier and so will not be repeated here. Slight vertical stress occurs in the 'shirt' back of the coveralls because of the increased length of the back in this stance. Distinctive diagonal folding/stressing radiates from the buttock region up to the underarm and through into the 'shirt' front of the coveralls. Close examination showed that in this stance, the armhole/sleeve tries to rotate toward the back (note the distance the shoulder seam has moved backwards off the top of the shoulder in Figure 14(c)) to give more length to the buttock area. As the sleeve twists and distorts, stress occurs in the front of the shoulder, adjacent to the sleeve cap.

SUMMARY

The stances which caused the observed maximum stress are crossing the arms in front with the hands on the opposite shoulders (the shirt and coverall upper back) and sitting with the knees and hips fully bent and the legs spread apart or squatting (crotch and upper inner leg of the trousers and coveralls).

The literature had indicated that fully bending the elbow, knee and spine would cause stress in the sleeve, trouser leg and back area respectively. Although this was found to be true, these stances did not cause as much stress in the garments as the above-mentioned ones. There are two reasons for this. First, at least two distinct tie points are required to cause stretching and thus stressing of the fabric between them. This criterion is satisfied when the arms are crossed in front, where the elbows are the two distinct tie points and when squatting where there are three tie points, the buttocks, the knees and the crotch. This criterion is not satisfied when the elbow and knee are bent since there is only one tie point, the elbow or knee, with the bottom of the sleeve or trouser leg being free to move up the arm or leg. Thus less stress occurs around the elbow and knee than in the upper back or crotch and upper inner leg areas. For the coveralls, the stance of a fully bent back does not cause as much stress as expected. Although two tie points (the shoulder and the crotch) exist in the coveralls, the shoulder of the coveralls does move back and the crotch moves up to minimize the stress over the fully bent back. This leads to the second reason; the garments used in these experiments and in fact, most conventional garments are designed with sufficient ease or length so that normal bending of the arm, leg and spine cause minimal stressing of the garment. However, except for shirts with pleats in the back or telescopic sleeves, conventional designs of long-sleeved shirts, trousers and coveralls do not include that extra ease which would be required to attain the described, extreme stances without stressing the garment.

Figures 15 and 16 show composite schematic 2-dimensional drawings of the stresses which occur in the trousers and the coverall when the subject squats with his hands at his sides. Figure 17 shows the location and direction of the maximum stresses in seams when squatting, when the arms are crossed in front and when the arms are stretched over the head.

These results generally agree with the literature review (Crow and Dewar, 1984) regarding the stances which cause maximum stresses. However, because we have developed a new technique for determining where stresses actually occur in clothing, identification of their location for

various stances is more detailed and precise than previously known. The literature identifies maximum stress in the trousers when the knees and hips are fully bent but does not include the added posture of spreading the legs apart to increase the stress in the crotch and inner leg area.

CONCLUSIONS

This paper has shown where stresses occur in clothing, and thus seams. It has also shown what stances cause the maximum stresses in typical CF clothing. It was found that crossing the arms in front with the hands on the opposite shoulders creates the greatest stress in the shirt or coveralls back. This stance imposes stress in the lower part of the back armhole seam. Raising the arms over the head creates a stress point at the back armscye. Squatting is the stance which causes the greatest stress in the trousers and coveralls, this occurring along the upper, inner leg and crotch area/seam.

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I. Emanuel and J.T. Barter. Linear Distance Changes Over Body Joints. WADC Technical Report 56-364, Wright-Patterson Air Force Base, Ohio, February 1957.

E.B. Frederick. Development of a Sewability Test for Cotton Fabrics. Tech. Res. J. 22, pp 687-692 (1952).

ACKNOWLEDGEMENT

We would like to thank Corporal Hooton for his cooperation, patience and endurance in this study.

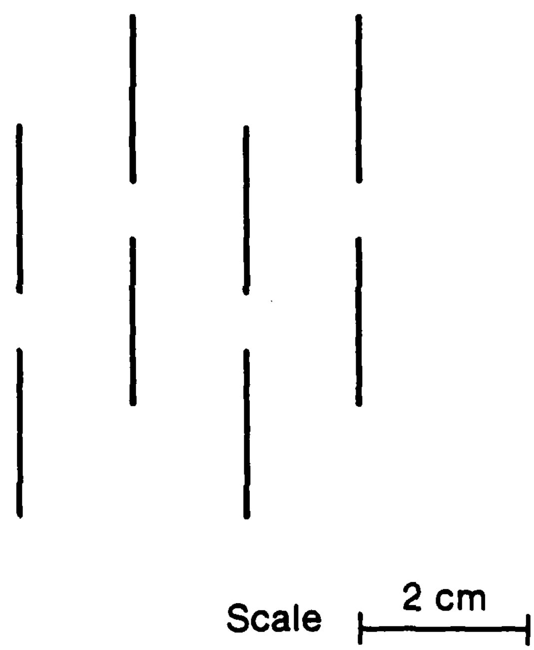


Figure 1: The Pattern of Slits Cut in the Rubber Sheeting.

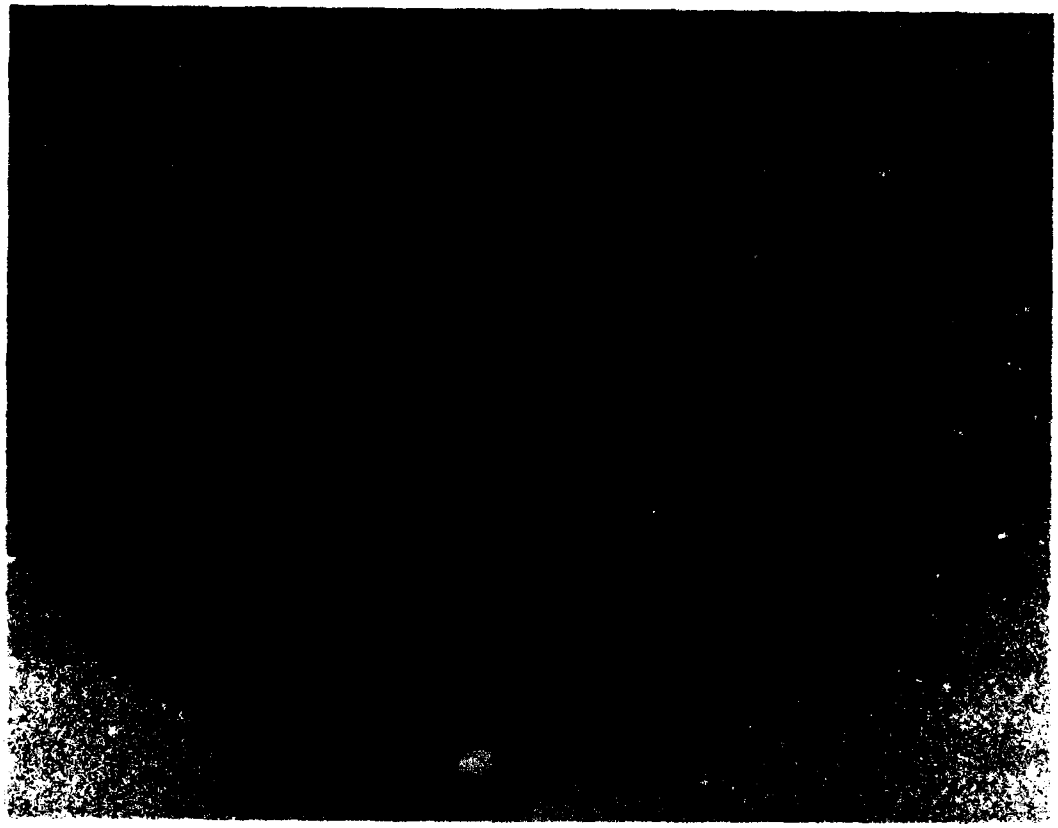
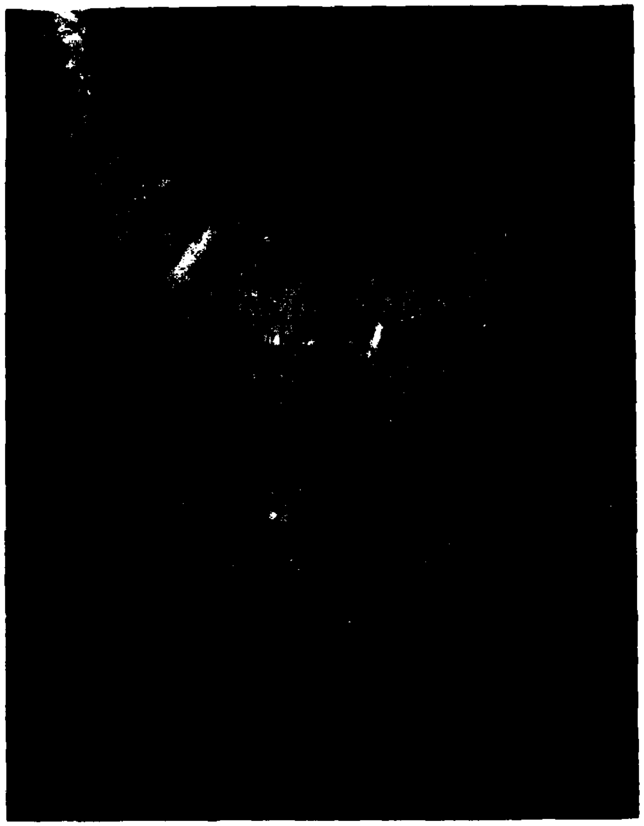


Figure 2: The Die Used to Cut Slits in the Rubber Sheeting.

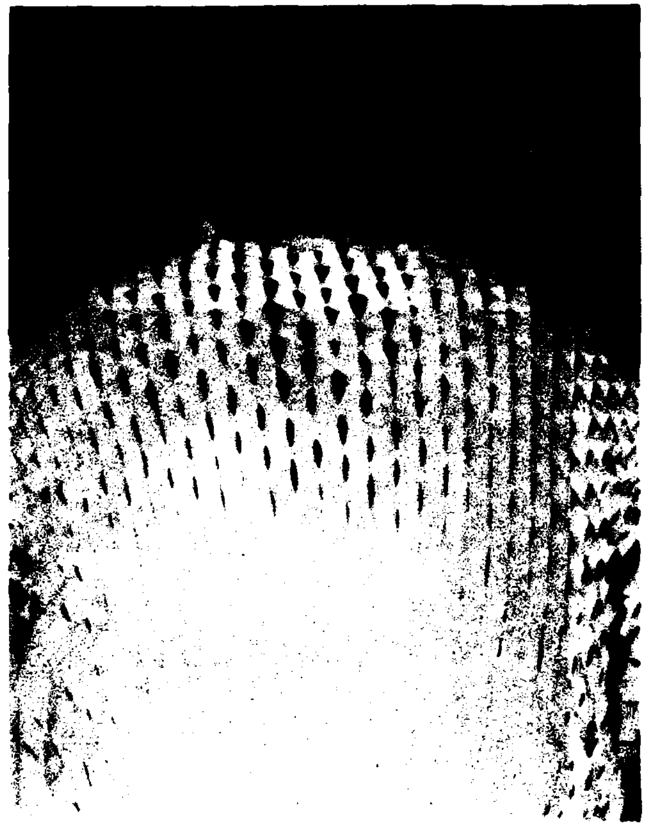
(a) The neutral position.



(b) Arms above the head.

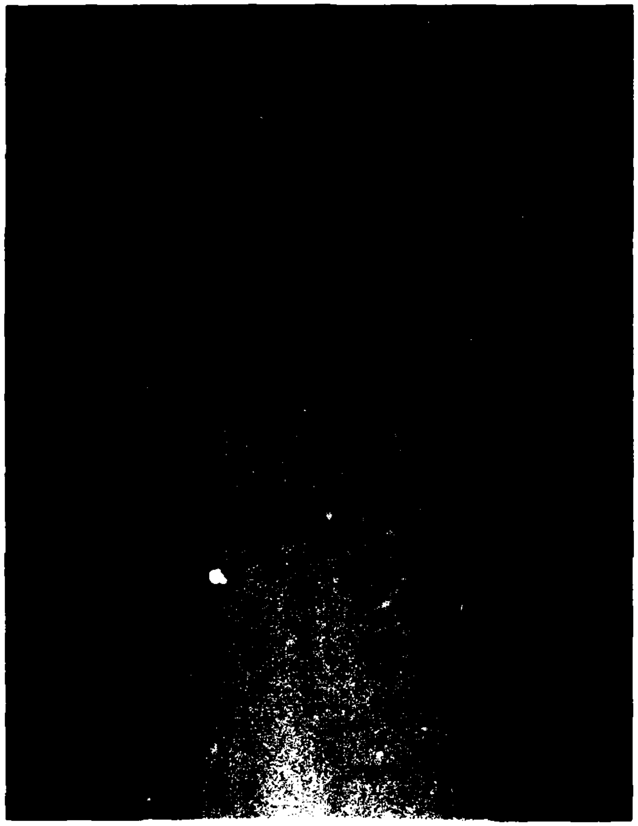
Figure 3: The Subject Wearing the T-shirt with the Slits Running Vertically Down the Back.

(c) Bending over, sideview.

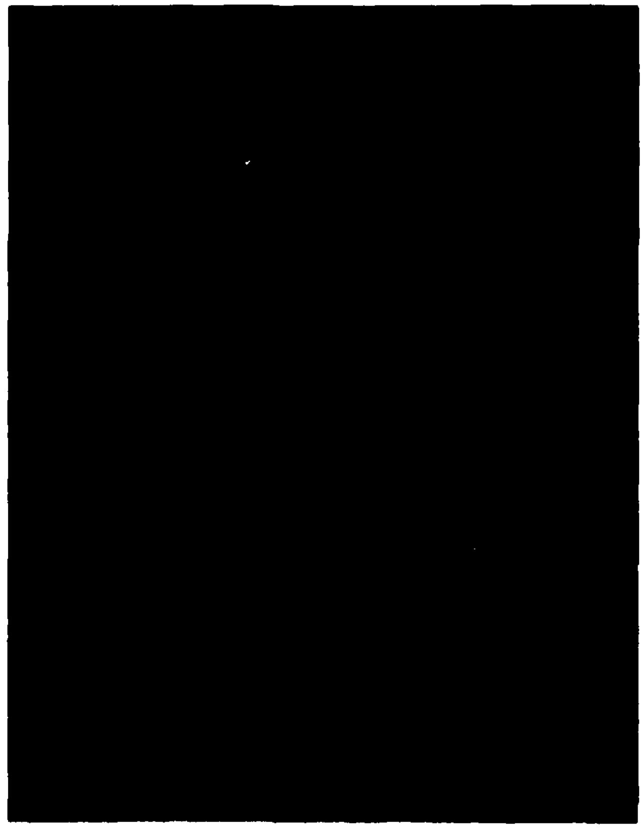


(d) Bending over, full backview.

Figure 3 Cont'd.

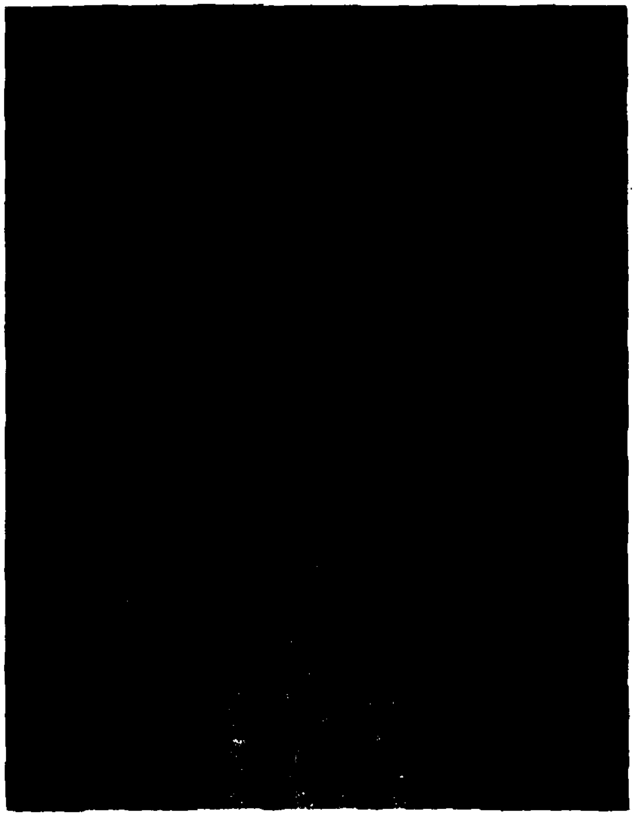


(e) Arms out straight in front.

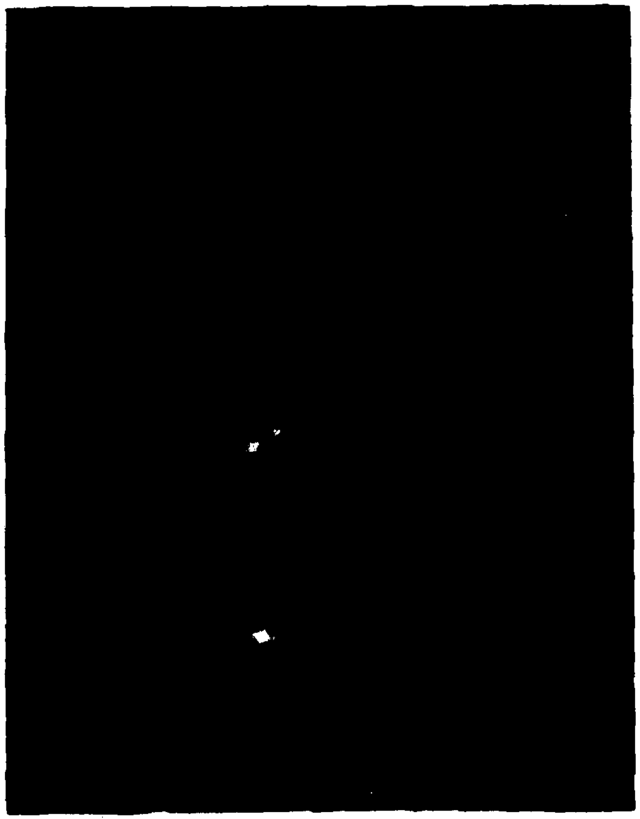


(f) Arms crossed in front parallel to floor,
hands on opposite shoulders.

Figure 3 Cont'd.



(a) The neutral position.



(b) Arms above the head.

Figure 4: The Subject Wearing the T-shirt with Slits Running Horizontally Across the Back.

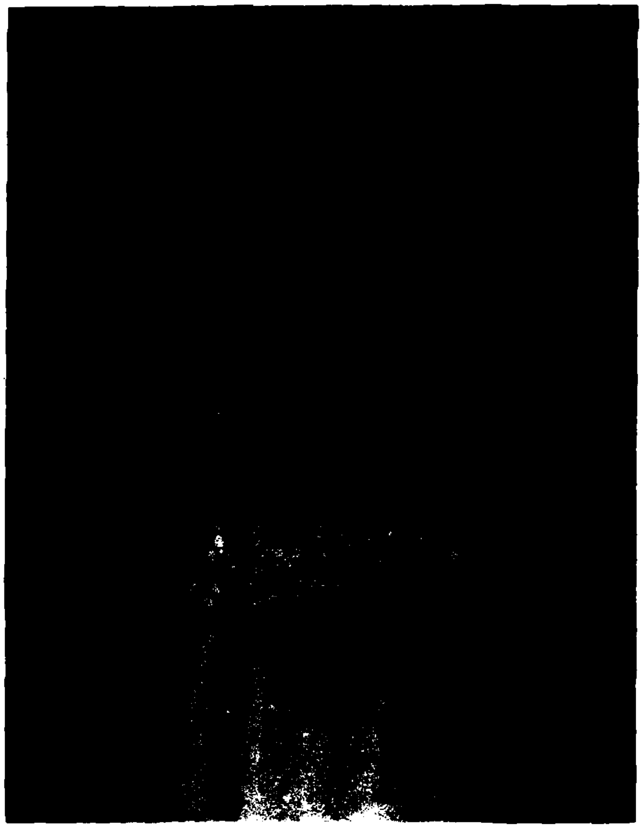
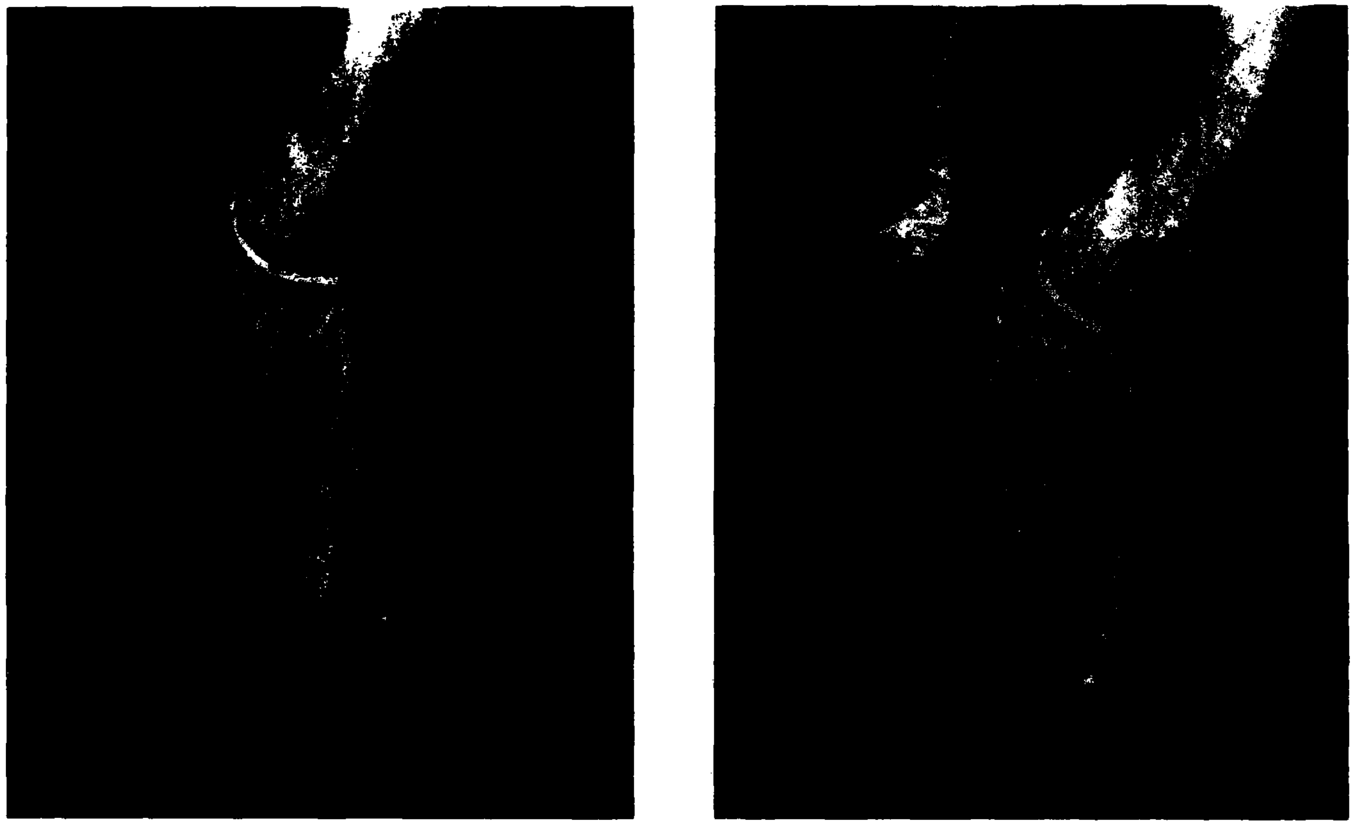


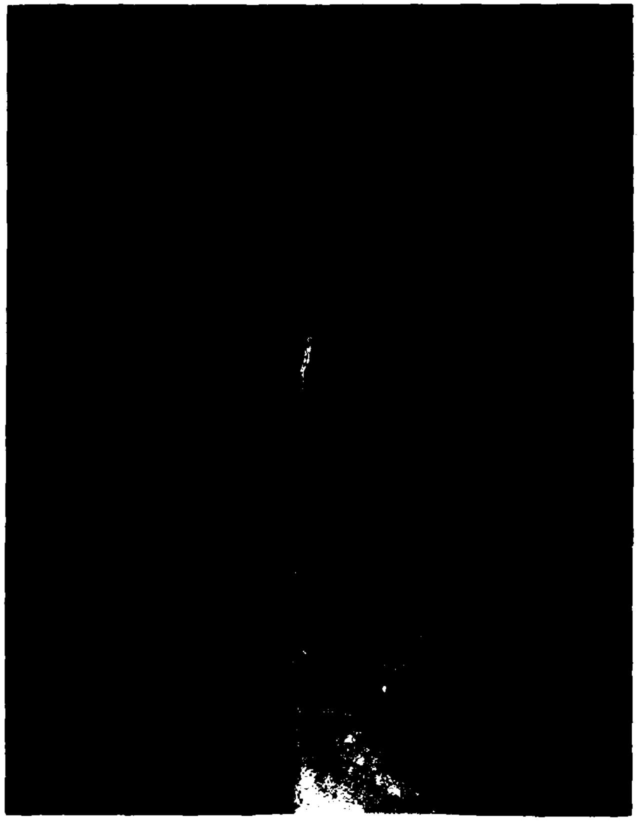
Figure 4 Cont'd. (c) Arms crossed in front, hands on shoulders.



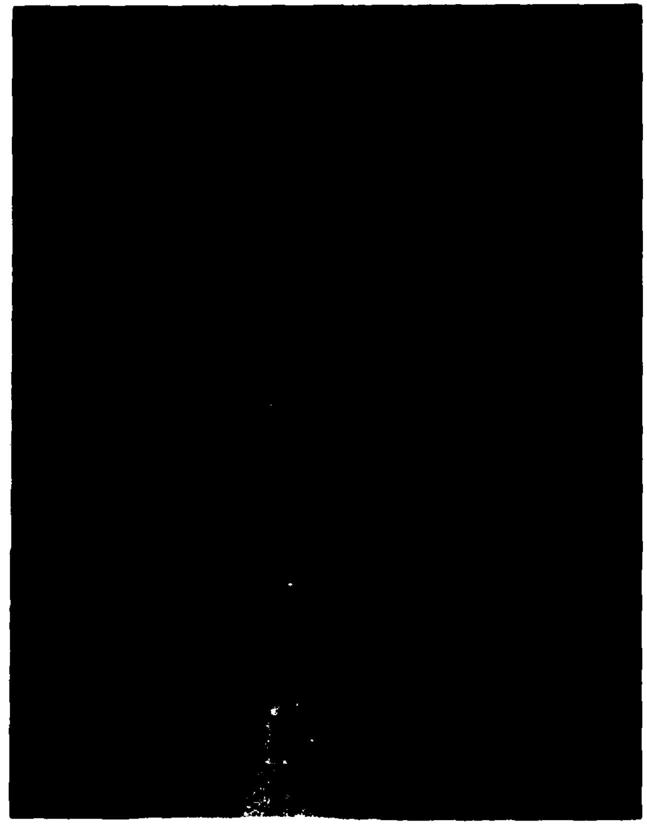
(i) vertical slits in sleeve. (ii) horizontal slits in sleeve.

(a) Arms above head

Figure 5: The Sideview of the Back and Arm.



(i) Vertical slits in sleeve.



(ii) Horizontal slits in sleeve.

(b) Arms crossed in front

Figure 5 Cont'd.

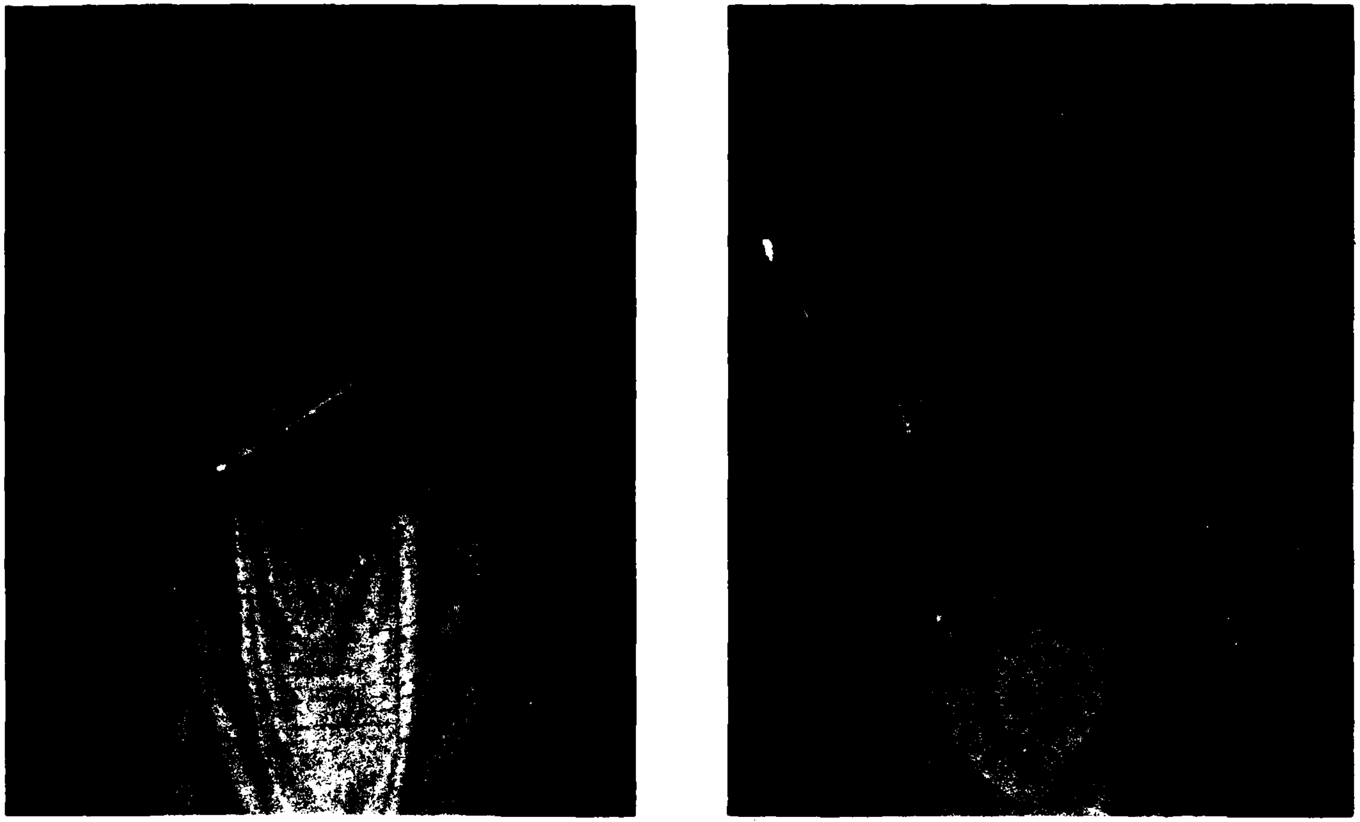
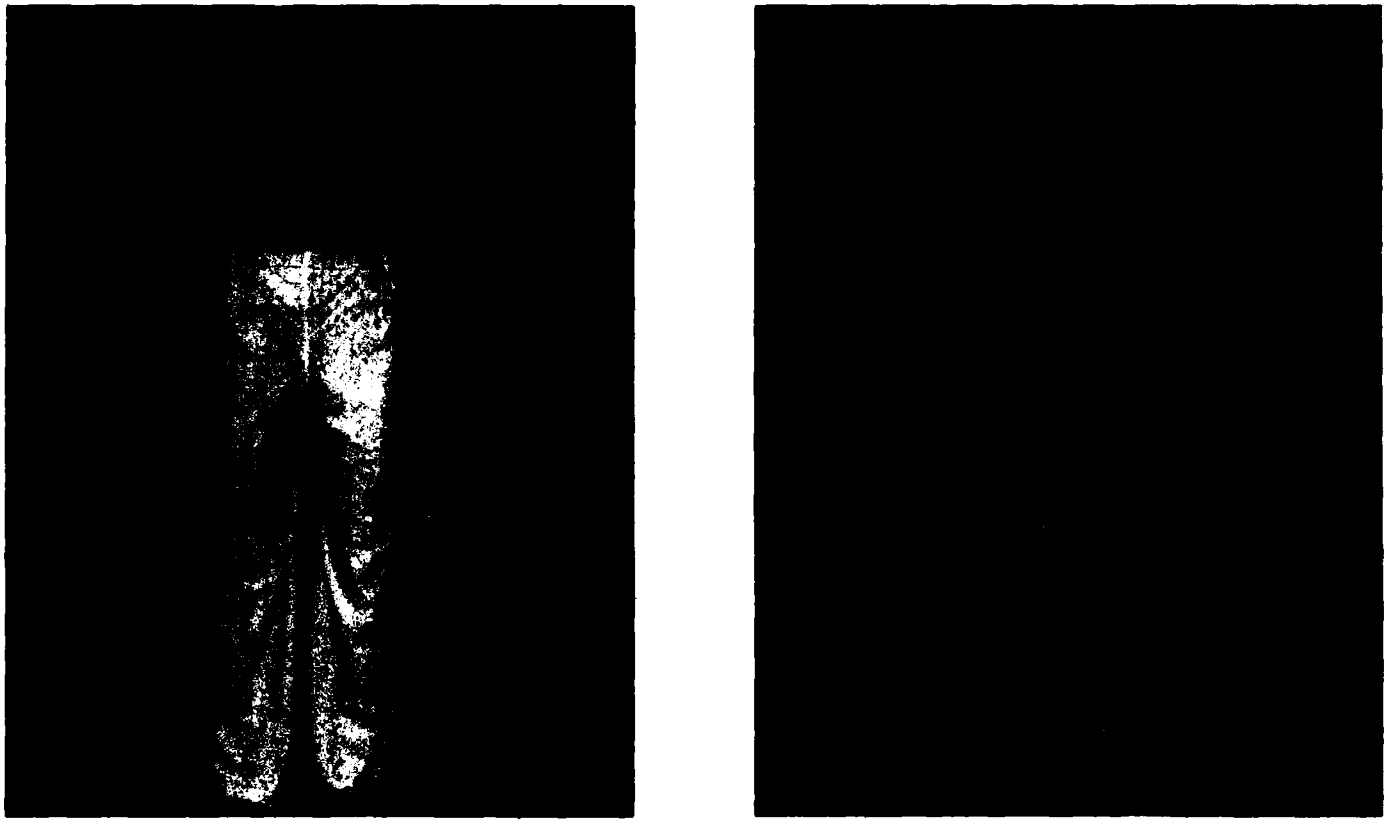
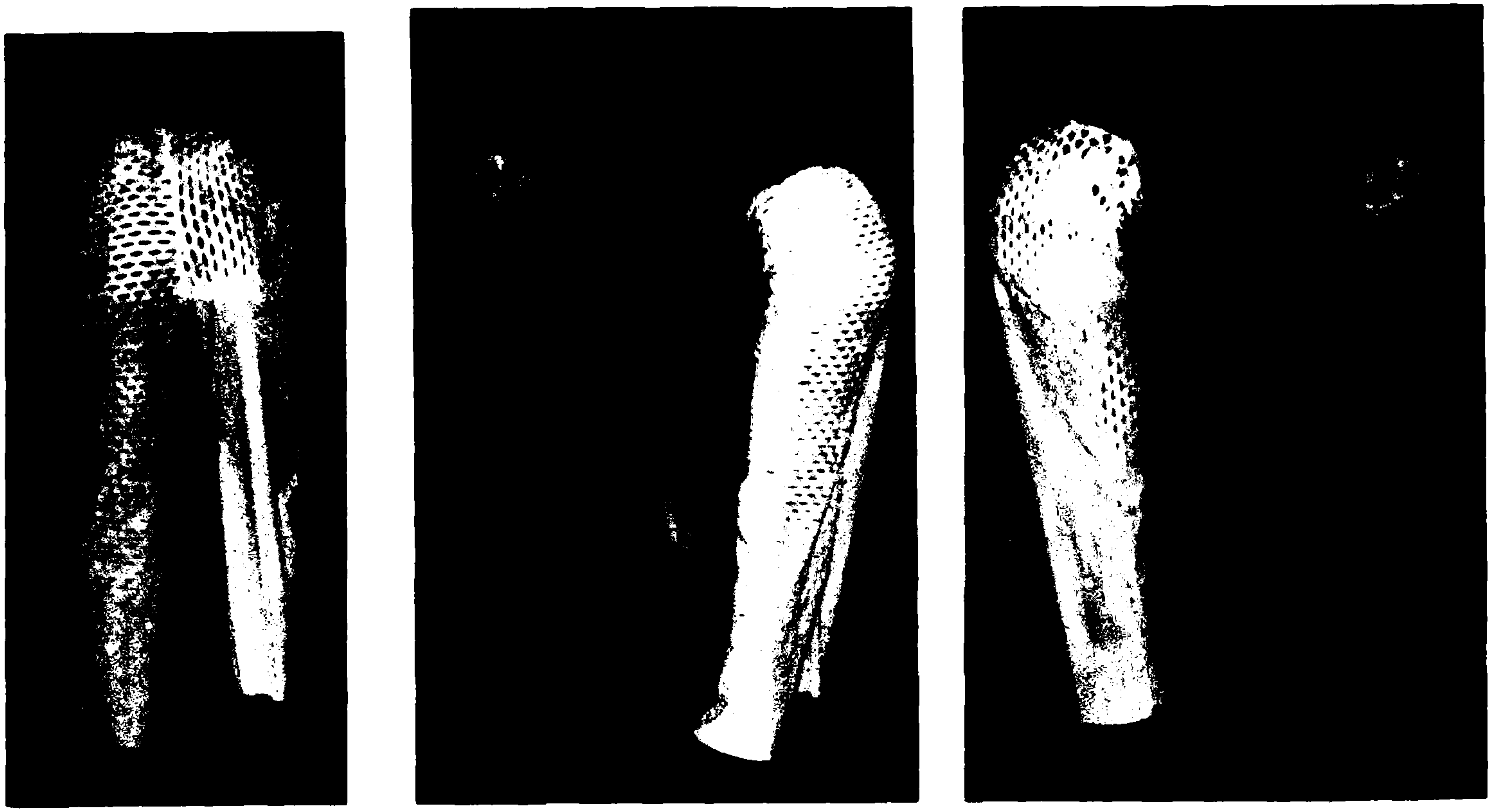


Figure 6: Stress Patterns for Elbow and Sleeves, Arms Bent.



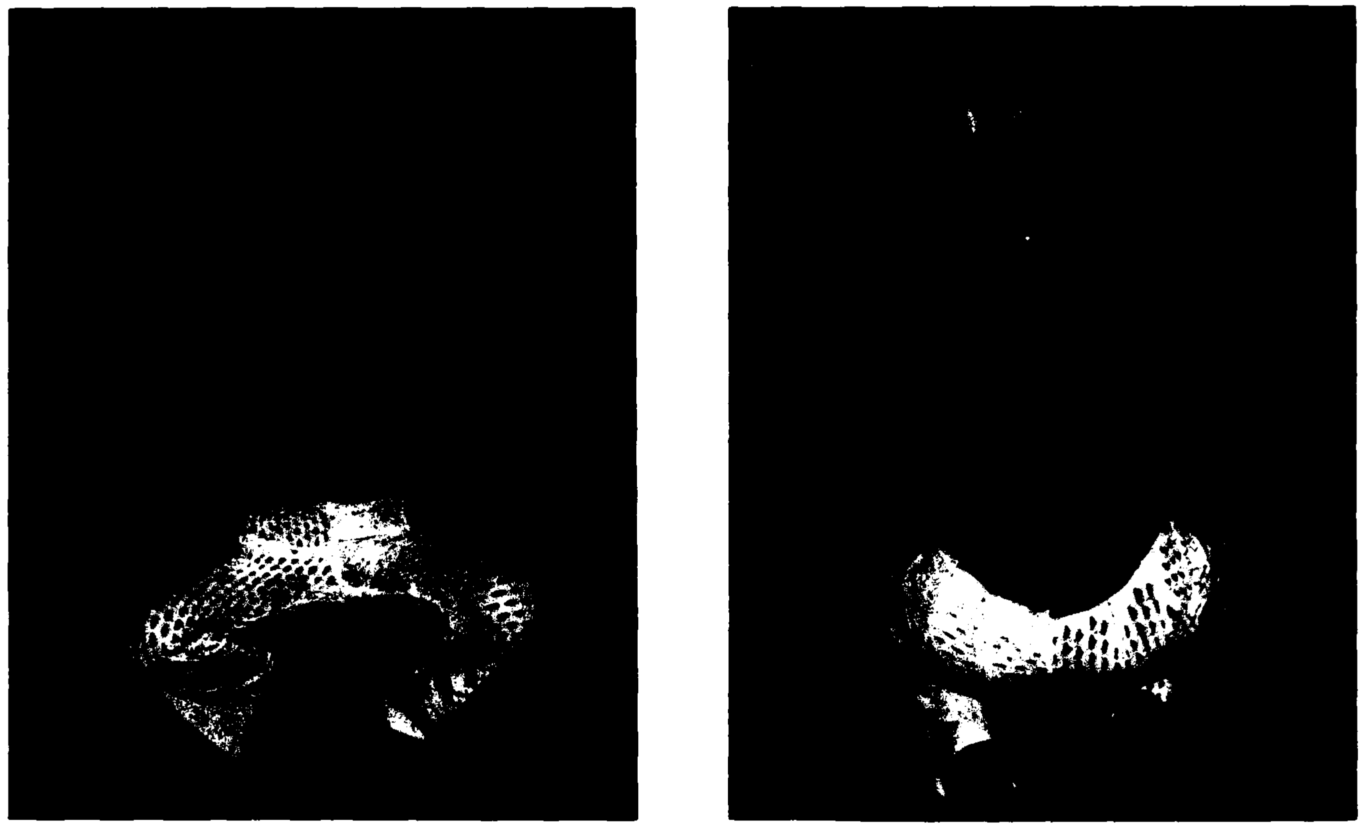
(a) Front View. (b) Rear View.

Figure 7: The Subject Wearing Trousers Standing in the Neutral Position.



(a) Rear View (b) Left Side (c) Right Side

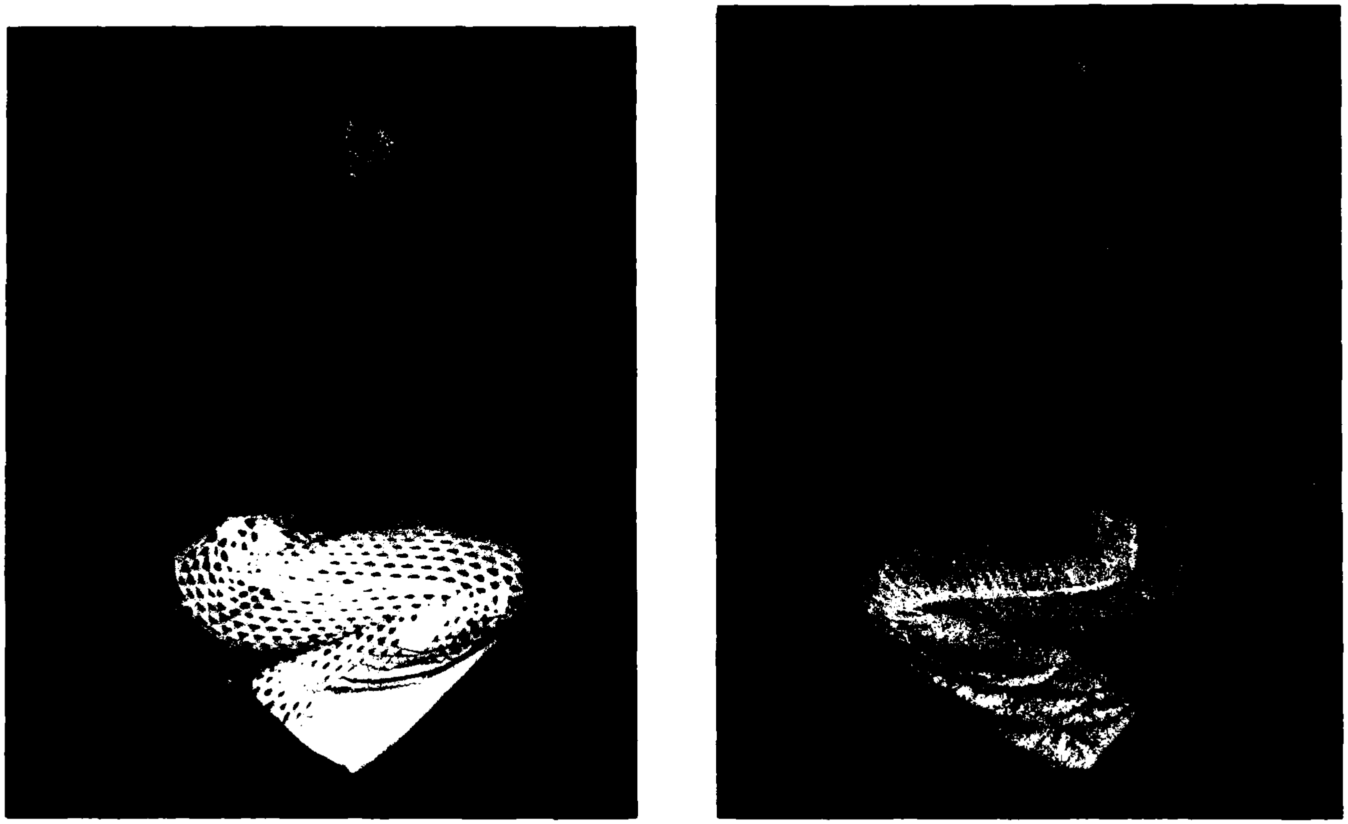
Figure 8: Stress in Trousers when the Subject Bends Over.



(a) Front View

(b) Back View

Figure 9: Stresses in Trousers when Subject Crouches.

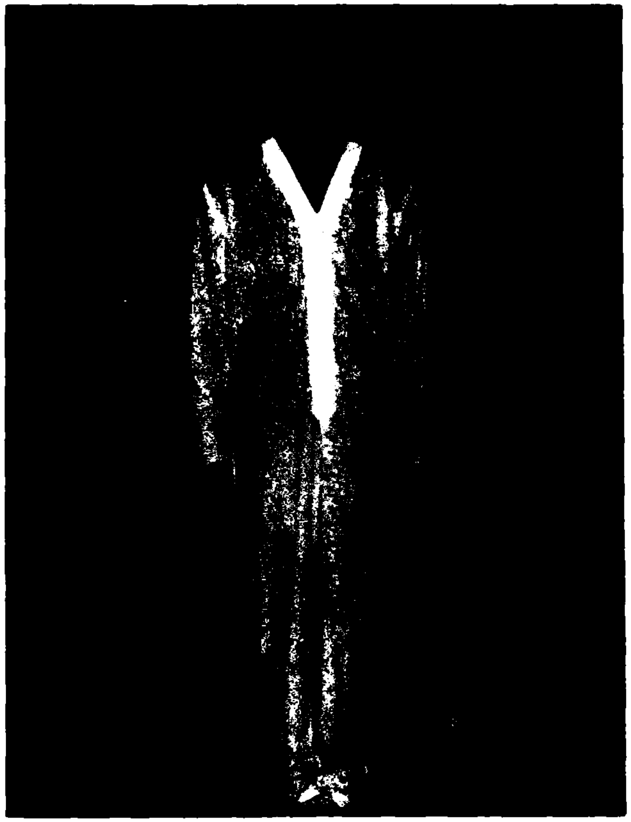


(c) Side view, vertical slits.

(d) Side view, horizontal slits.

Figure 9 Cont'd.

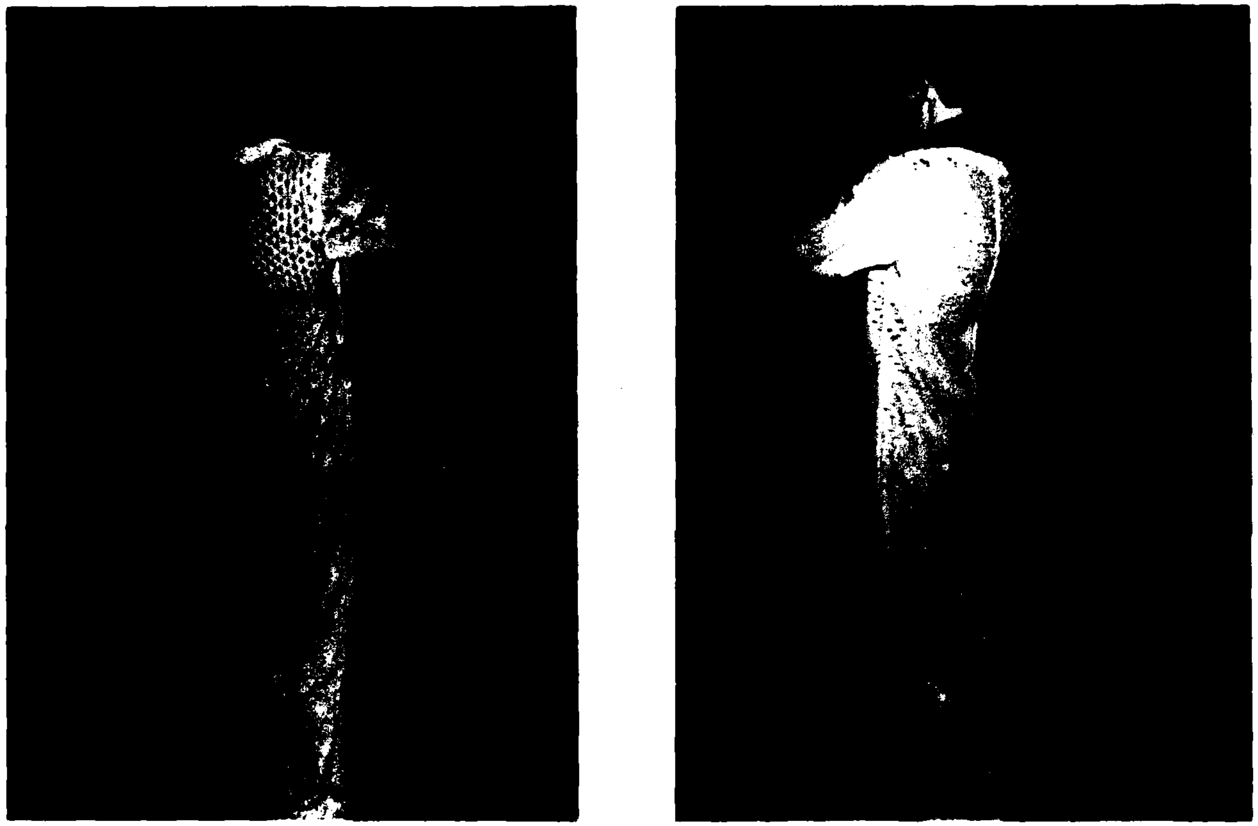
Figure 10: Stresses in Trousers in Lower Hip, Crotch and Lower Leg Areas.



(a) Front View

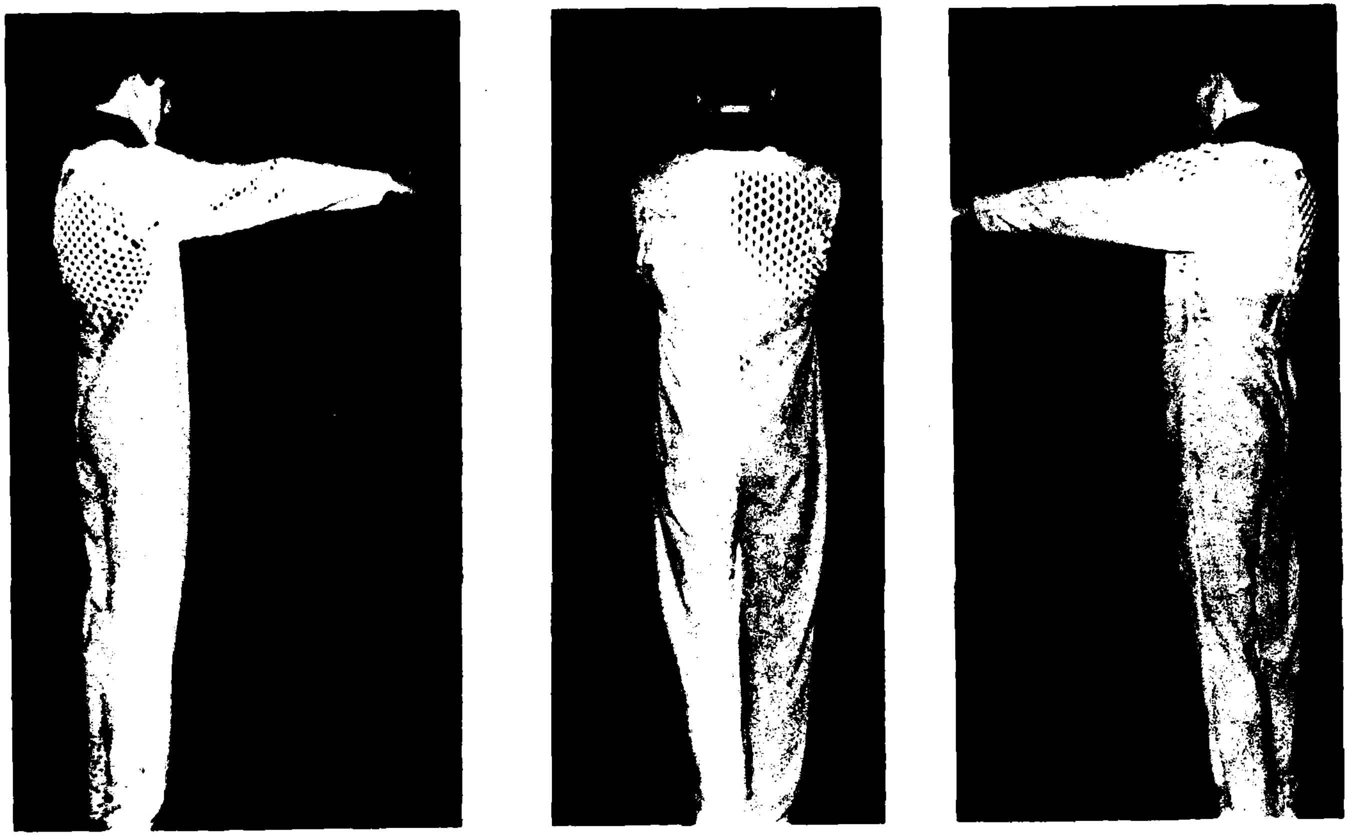
(b) Back View

Figure 11: The Subject Wearing Coveralls Standing in the Neutral Position.



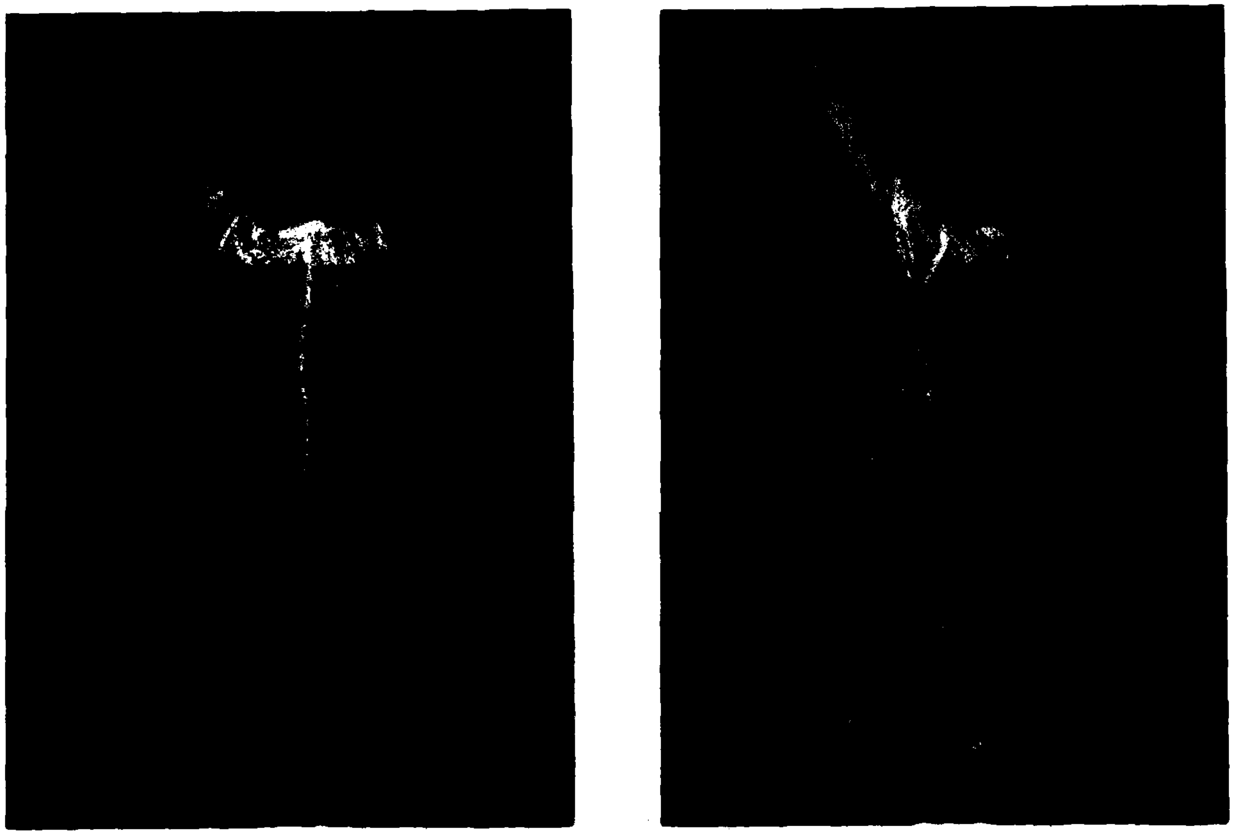
(a) Arms crossed in front.

Figure 12: Subject with Arms in Various Positions.



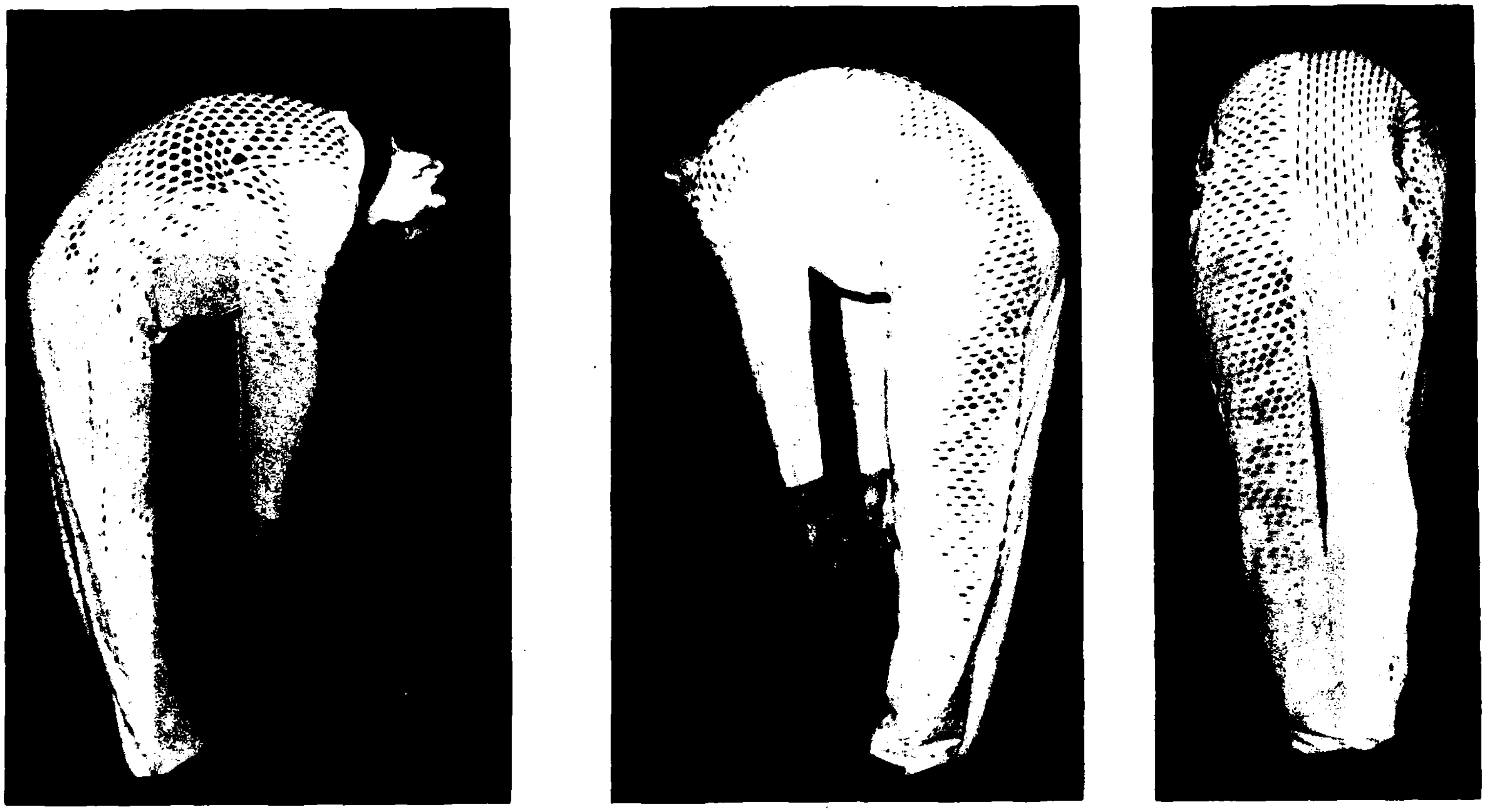
(b) Arms outstretched.

Figure 12 Cont'd.



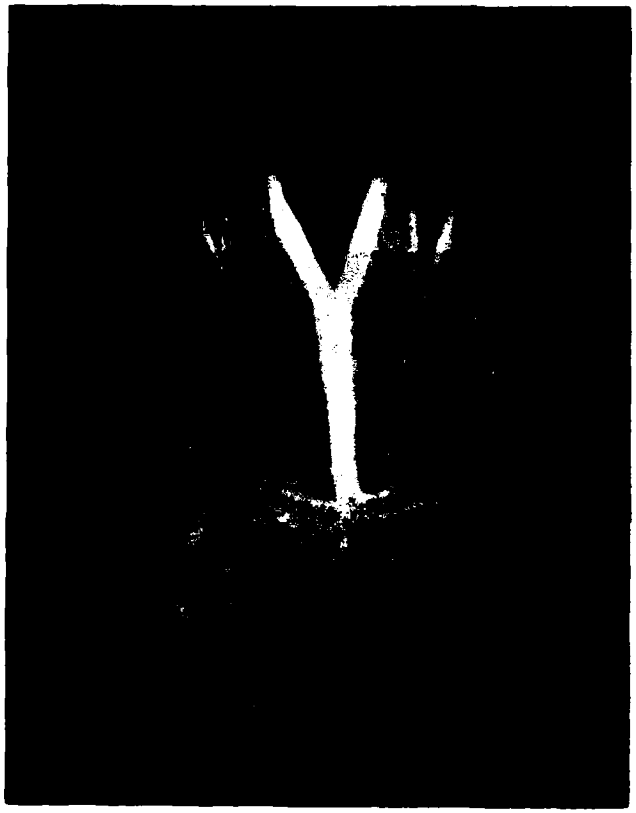
(c) Arms over head.

Figure 12 Cont'd.

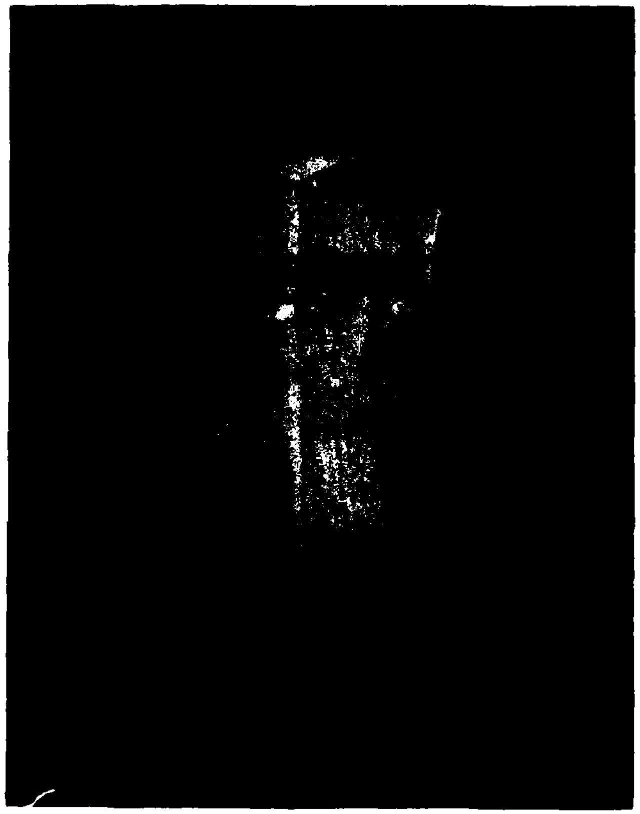


(a) Right side view. (b) Left side view. (c) Rear view.

Figure 13: Subject Bending Over.

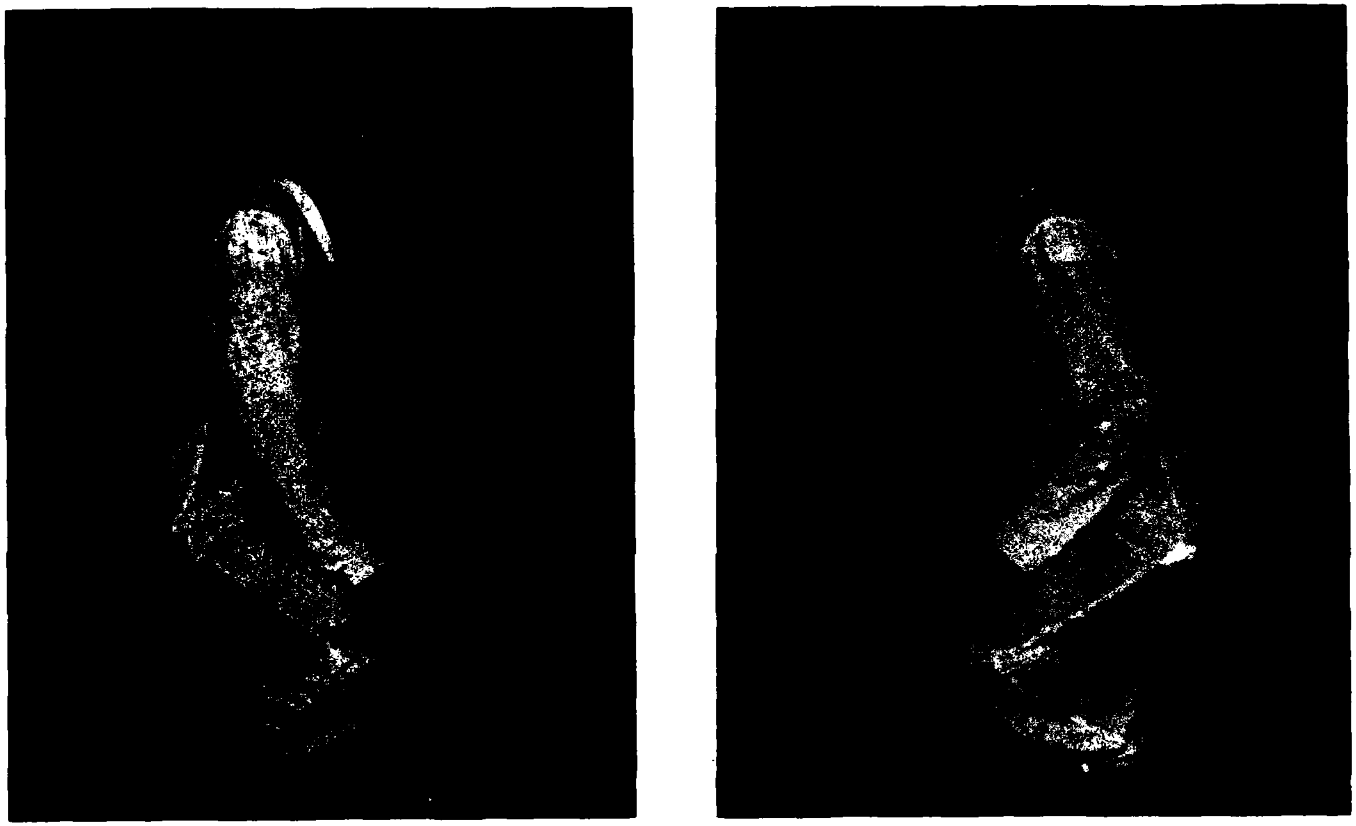


(a) Front View



(b) Rear View

Figure 14: Subject Crouching.



(c) Right Side

(d) Left Side

Figure 14 Cont'd.

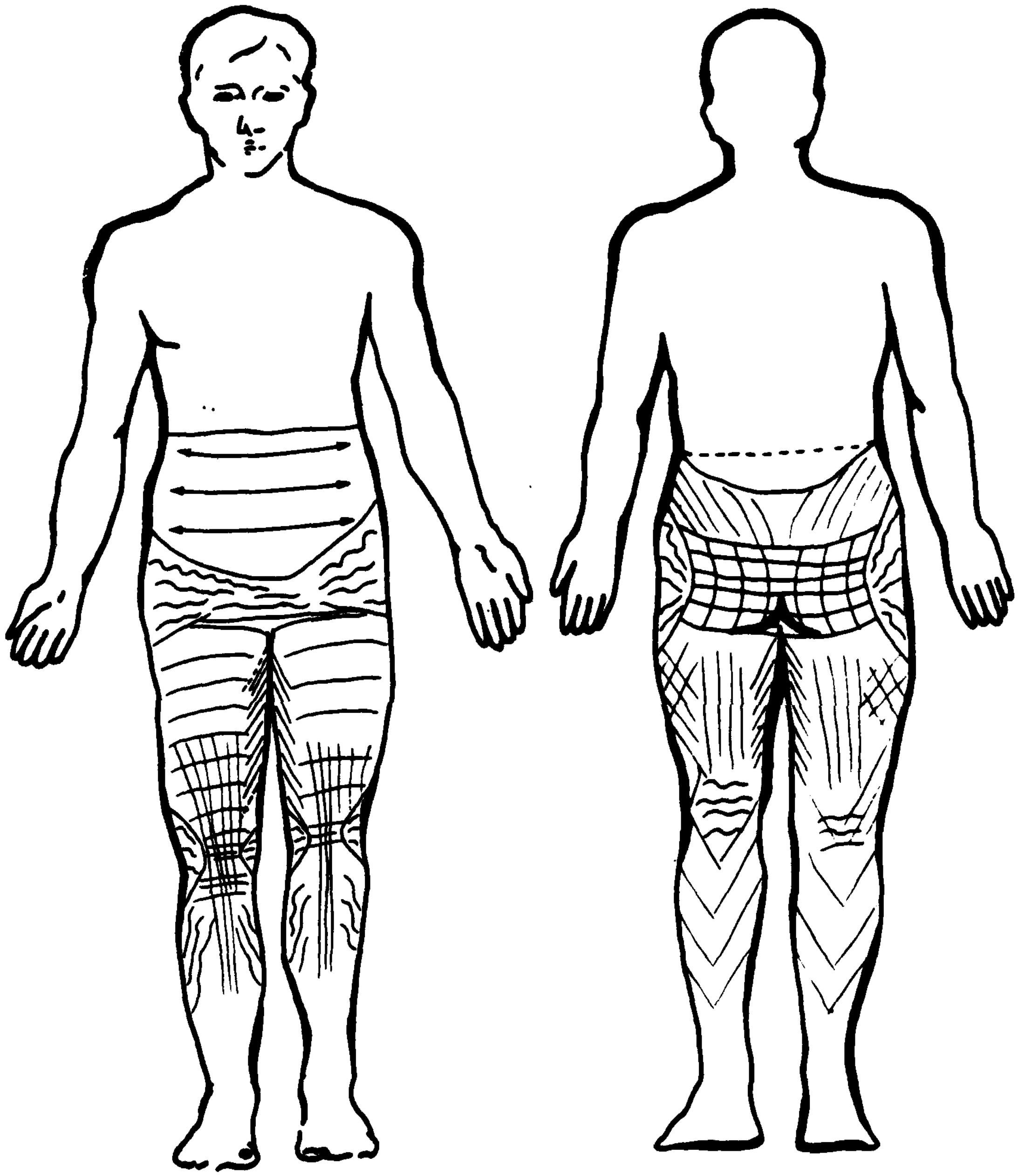


Figure 15: A Composite Schematic Drawing of the Stresses which Occur in the Trousers when Squatting.

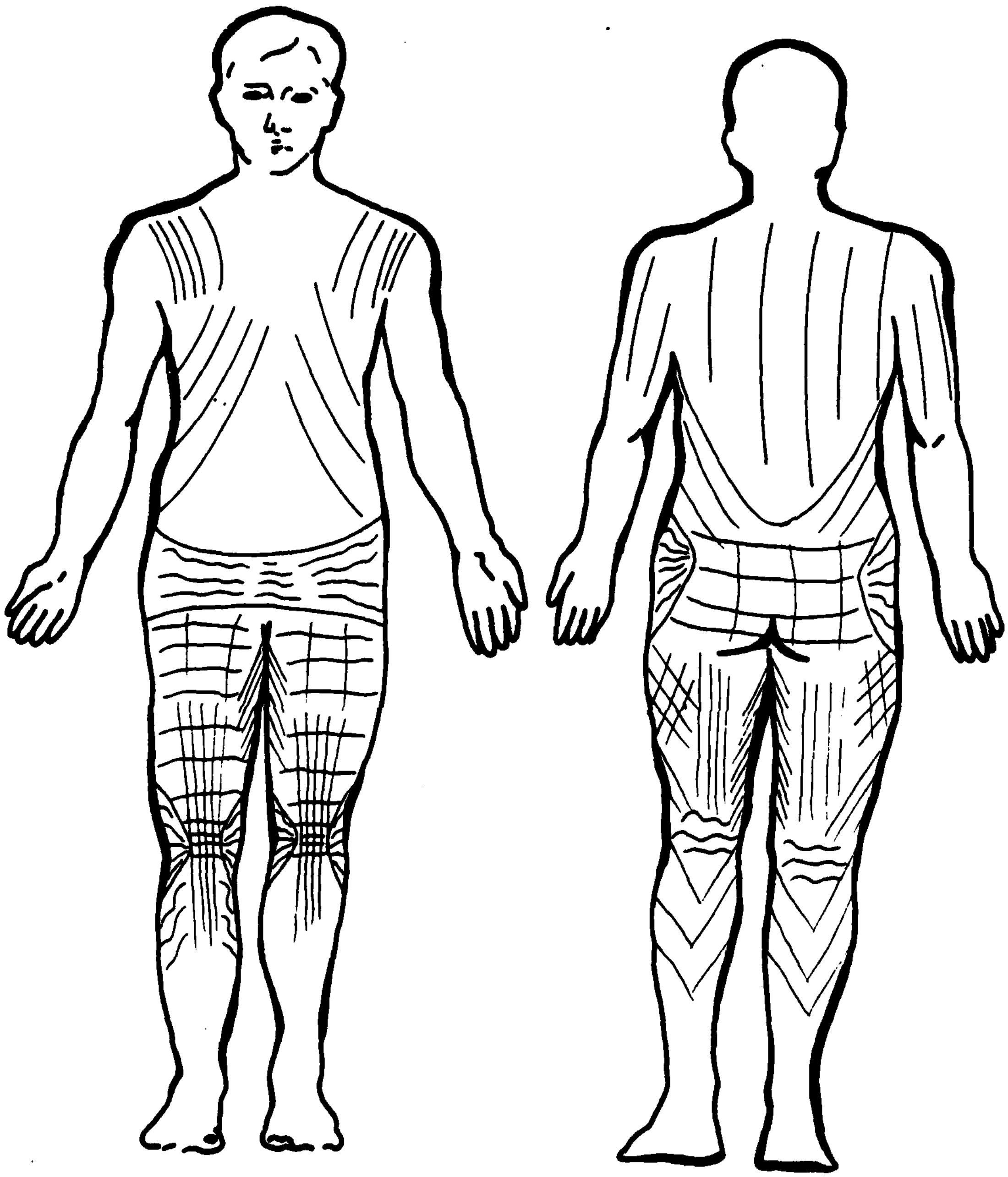


Figure 16: A Composite, Schematic Drawing of the Stresses which Occur in the Coveralls when Squatting.

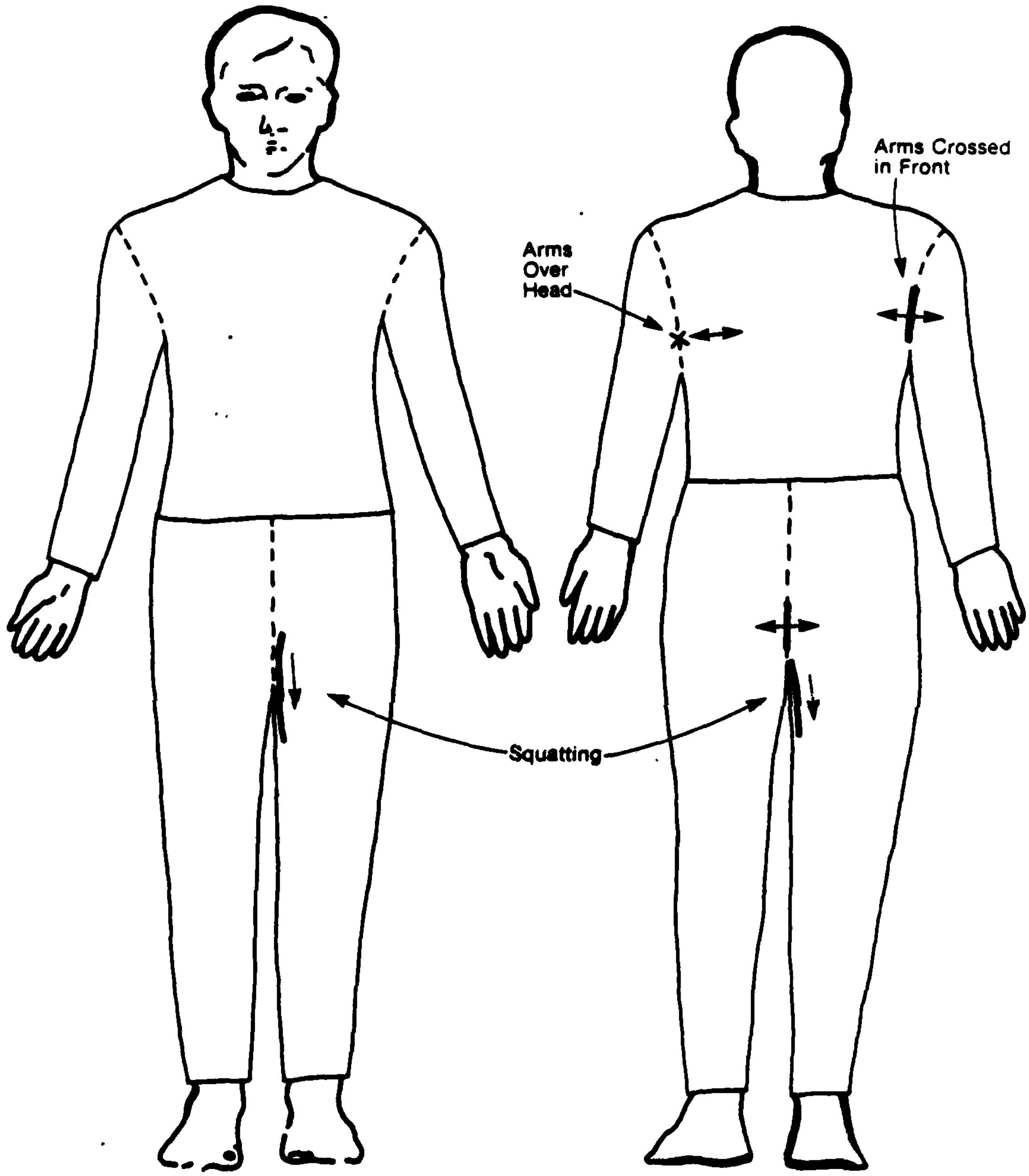


Figure 17: Location and Direction of the Maximum Stress Regions in Seams of Typical CF Clothing.

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13. ABSTRACT

This paper reports the results of a study to determine where stresses occur in clothing, and thus seams, and what stances cause the maximum stresses in typical Canadian Forces clothing. It was found that crossing the arms in front with the hands on the opposite shoulders creates the greatest stress in the shirt or coveralls back. This stance imposes stress in the lower part of the back armhole seam. Raising the arms over the head creates a stress point at the back armscye. Squatting is the stance which causes the greatest stress in the trousers and coveralls, this occurring along the upper, inner leg and crotch area/seams.

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